In-Situ Bioremediation in a Low-Permeability Formation Through Ground Water Recirculation

Interim Summary Report for the Treatment Facility D Helipad
*In-Situ* Bioremediation Treatability Test

June 15, 2012

Lawrence Livermore National Laboratory

Environmental Restoration Department

Background

- Remediation of high contaminant concentration and low-permeability aquifers continues to be a significant challenge for site-owners. One such example is the former Helipad at the Lawrence Livermore National Laboratory in Livermore, California, where chlorinated solvents were released to ground water during site activities in the 1950s. Dual-phase extraction of soil vapor and ground water over the last decade reduced Trichloroethylene (TCE) concentrations significantly, but residual TCE concentrations of approximately 600 μg/L still persist in the low-permeability sediments.

Site Location
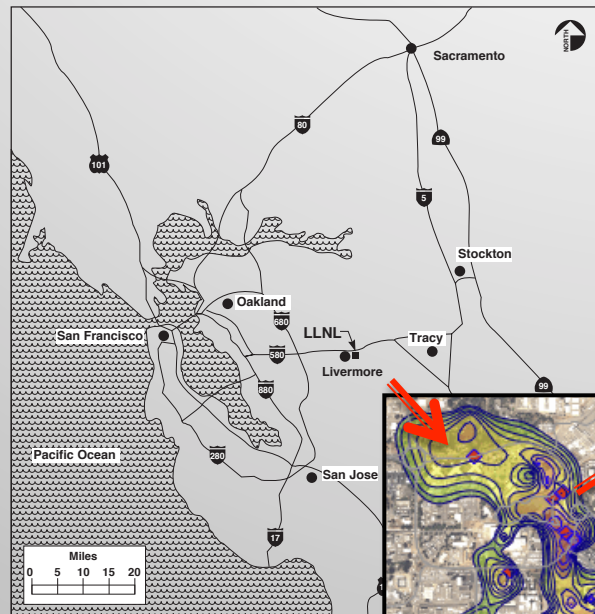
LLNL Site Location and volatile organic compounds (VOC) plume map

Former Helipad

20 ft

N
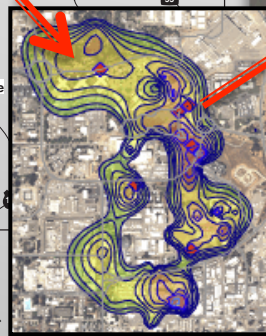
🔵 Extraction Well

🟡 Injection Well

🟢 Monitoring Well

Objectives

1) Perform a treatability test at the former Helipad to determine if a ground water circulation cell can be used to implement in-situ bioremediation of a well-oxygenated low-permeability aquifer and

2) compare the treatability test results to ex-situ remediation technologies.
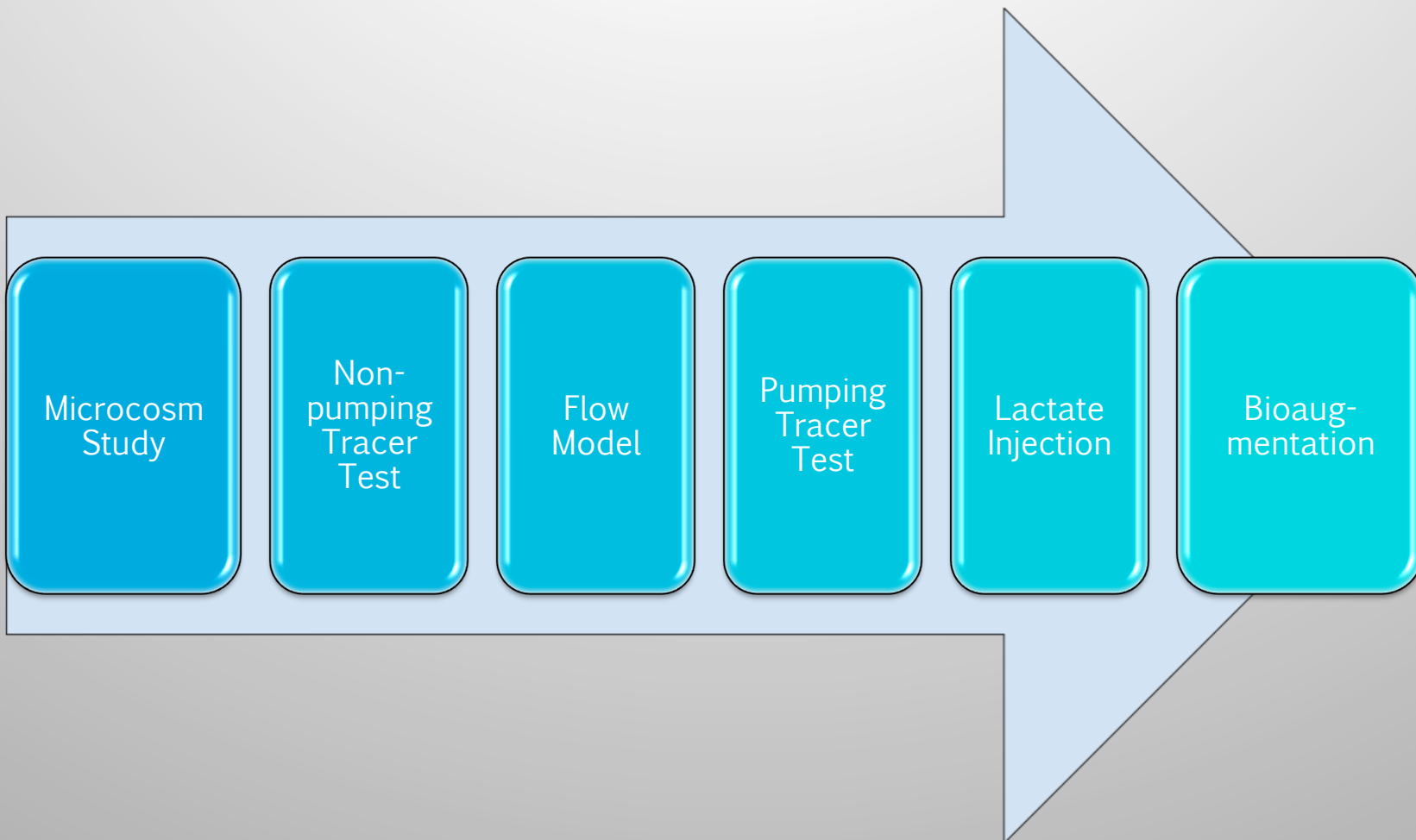
The dataset resulting from this study will be used to determine if implementing in-situ bioremediation will accelerate cleanup times, compared to the dual-phase extraction previously used at this site. The results will also help address the larger issue of how to practically implement circulation cells in low-permeability aquifers

Why In-Situ Bioremediation?
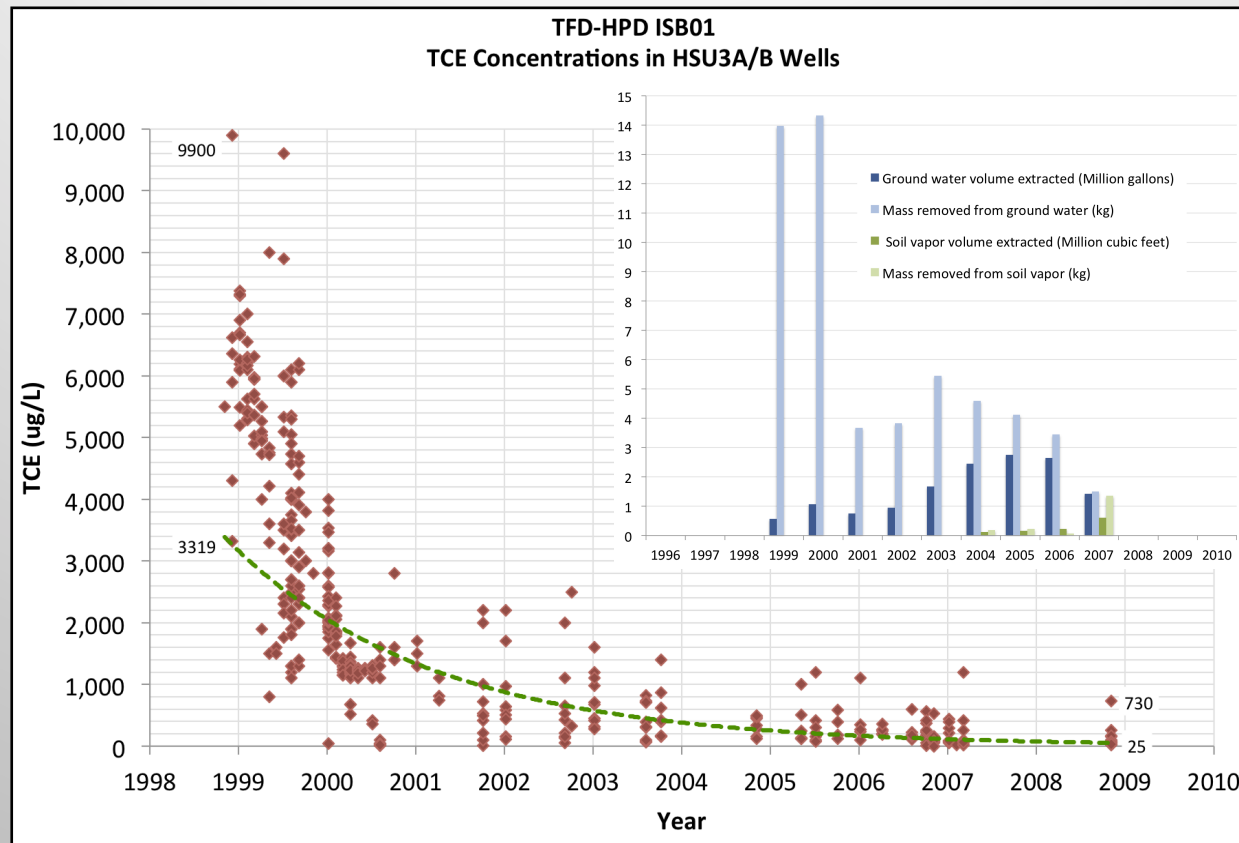
TCE Concentrations vs. time in Helipad wells. Inset shows volume of groundwater and soil vapor extracted, and TCE mass removal. By 2009, the ex-situ remediation system had already reached asymptotic concentration levels, further emphasizing the importance of the in-situ biotreatability study at this site.
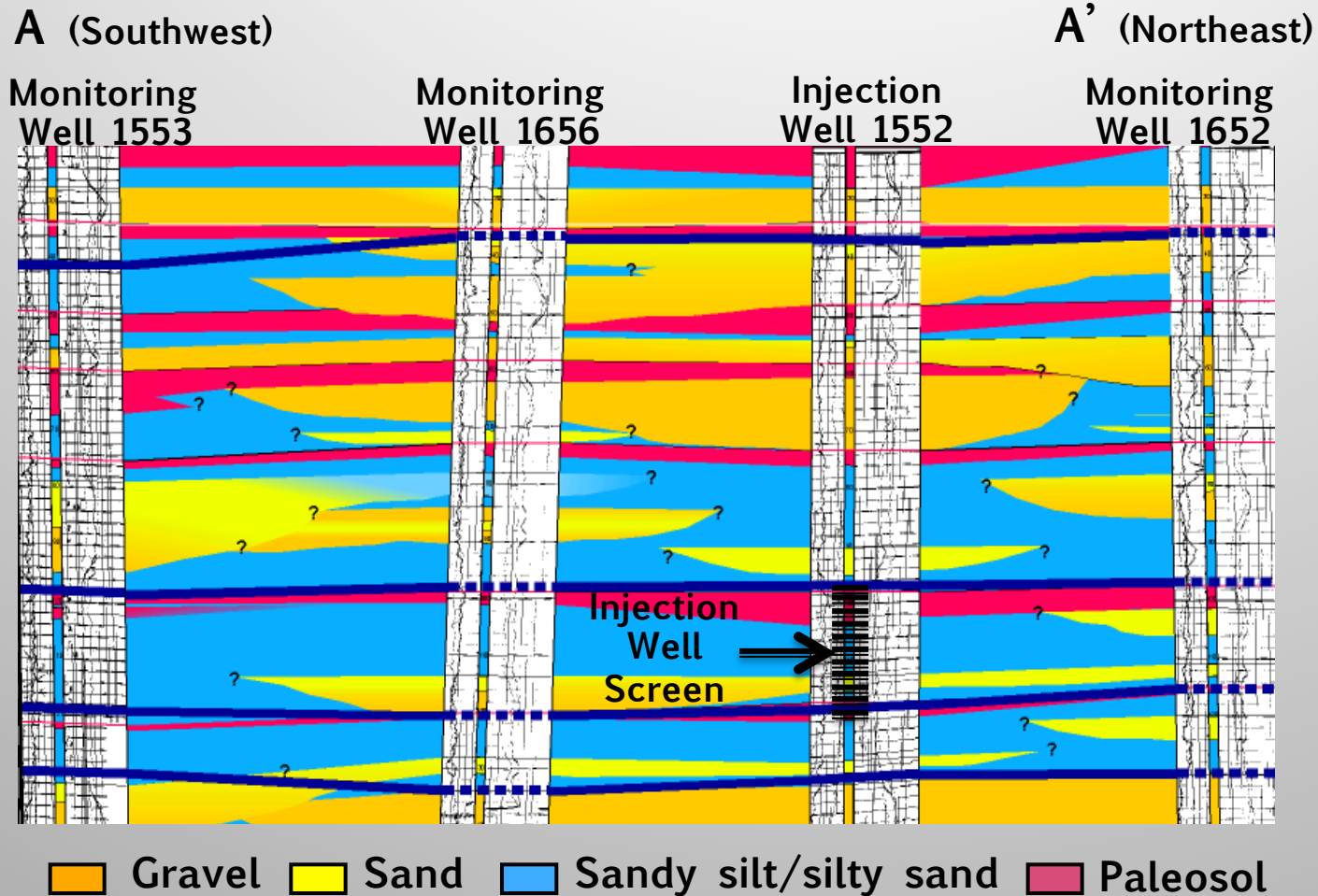
Approach

Microcosm Study → Non-pumping Tracer Test → Flow Model → Pumping Tracer Test → Lactate Injection → Bioaugmentation

Site Geology

- The injection well, extraction wells, and performance monitoring wells are screened across lower-permeability sandy silt to clayey silt alluvial fan deposits of Plio-Pleistocene age. While primarily composed of fine-grained sediments, occasional deposits of silty sands and silty gravels are also found within the sequence.

Site Geology (continued)

A (Southwest)   A' (Northeast)

Monitoring   Monitoring   Injection   Monitoring
Well 1553   Well 1656   Well 1552   Well 1652

Injection
Well
Screen

Gravel   Sand   Sandy silt/silty sand   Paleosol

Microcosm Study

Microcosm Laboratory Study

Microcosms were established with freshly-collected Site ground water and sediment.

➢ Electron donors tested including ethanol, lactate and emulsified soy bean oil.

Results

➢ All electron donors promoted biological activity.
➢ Bioaugmentation is required to achieve complete dechlorination to ethene.

LLNL
Anaerobic Intrinsic
Control
5

Microcosm Study (continued)

Typical Result: Lactate Amended Microcosm
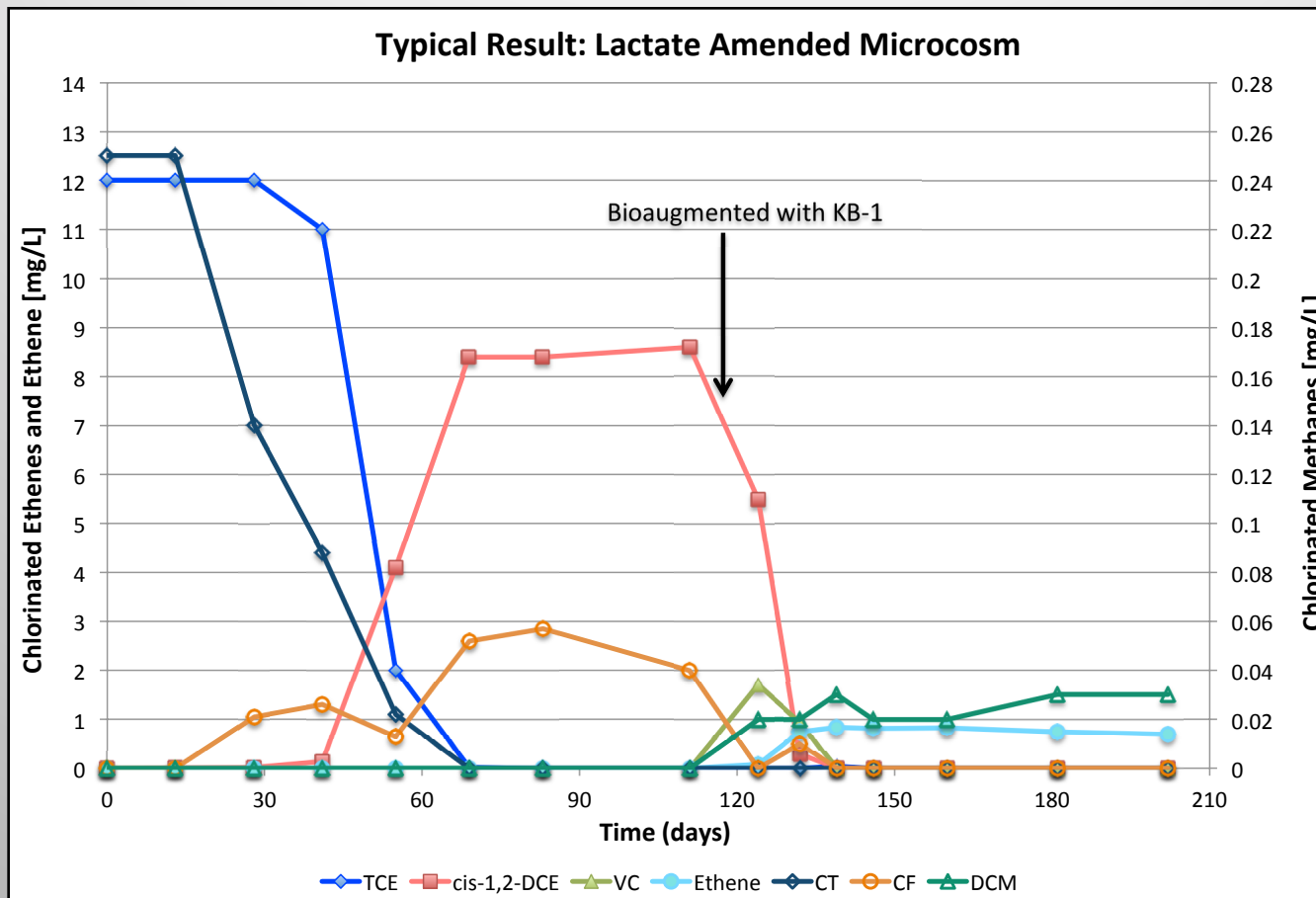
Non-pumping Tracer Test and Transport Model

Tracer Test under Non-pumping Conditions

➢ Hetch-Hetchy reservoir water with isotopic and electrical conductivity signatures distinct from native ground water was injected into central well W-1552.

➢ Conductivity data indicated tracer arrival at closest monitoring well after 2-3 days of injection.

➢ Majority of 11 monitoring wells responded within 7 days of tracer injection.

Results

➢ Target zone determined to consist of a lower-permeability sequence enveloping discrete, high-permeability, preferential flow pathways.

➢ Circulation cell selected as best design for implementing conditions favorable for in-situ remediation.

Non-pumping Tracer Test and Transport Model (continued)

Flow Model
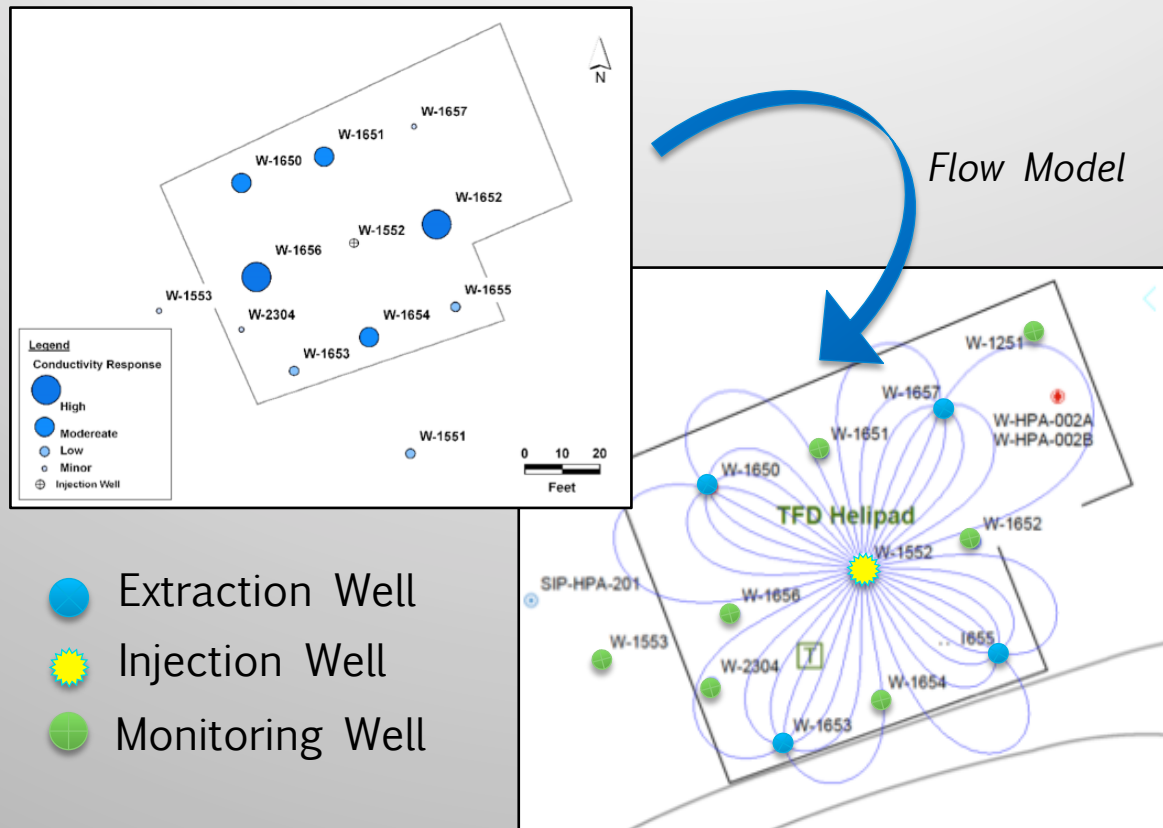
Extraction Well

Injection Well

Monitoring Well

# Pumping Tracer Test

Tracer Test under Pumping Conditions

➤ Fluorescein dye tracer (8 pounds) injected into central well W-1552 while circulation cell was operating.

Results

➤ Fluorescein tracer curves show rapid arrival of fluorescein dye tracer in extraction wells W-1650 & W-1653 and monitoring well W-1652 and illustrate how preferential flow pathways control flow in the circulation cell.

Powder   W-1552   W-1650   W-1653

Pumping Tracer Test (continued)
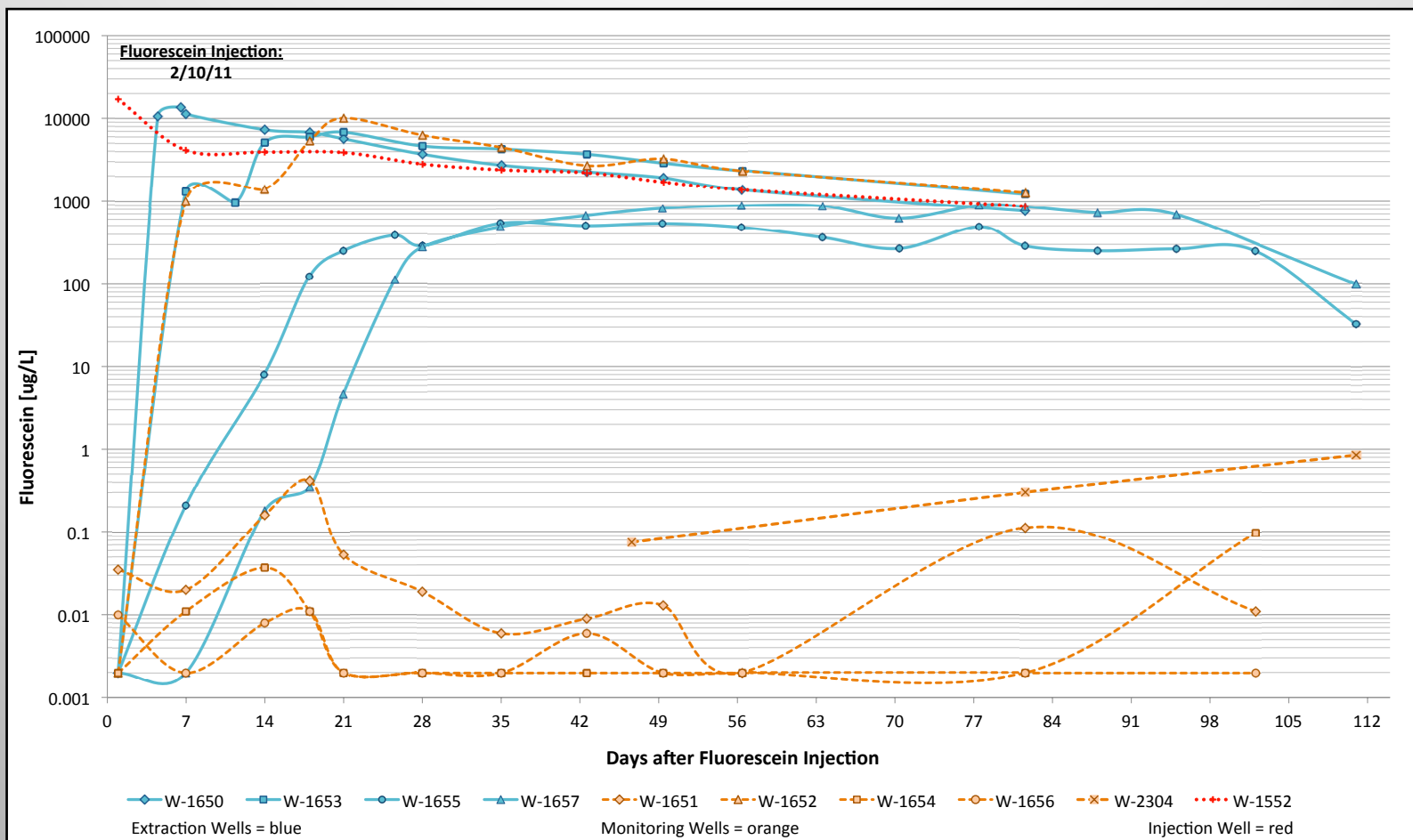
Well Field Infrastructure

Circulation Design

➢ Extraction pattern was chosen (extracting from four corner wells, injecting into center well) to minimize intrusion of upgradient, aerobic water into the circulation cell.

➢ Well field was operated in circulation mode for approximately 6 months to achieve a uniform distribution of TCE concentrations and to optimize extraction well pumping rates.

➢ Injection rate at W-1552 ranges between 0.5 and 1.0 gallons per minute.

Argon Injection

➢ Argon is being injected on a weekly basis at the well head of the extraction wells, monitoring wells and injection well to displace any oxygen and minimize biofouling.

Well Field Infrastructure (continued)
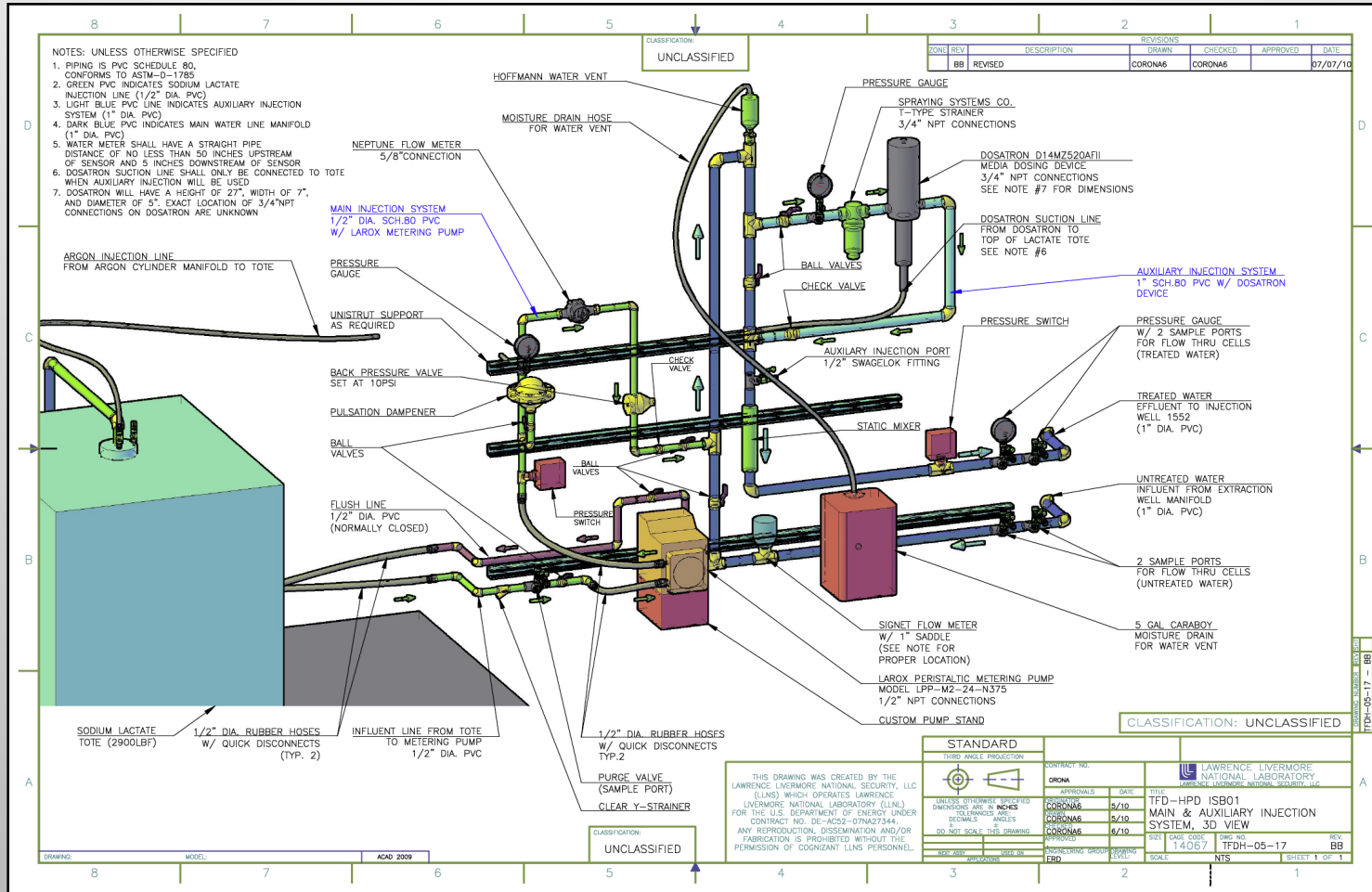
The circulation system is controlled by an automated system that allows injection of sodium lactate using a flow actuated dosing pump. The extraction and injection flow rates are controlled using water levels in extraction and injection wells and the system is interlocked to operate 24/7.

Lactate Injection

## Electron Donor Requirements

➢ Sodium lactate (60% weight/weight) was chosen as the electron donor, based on its favorable results in the microcosm study.

➢ Estimated dose: 320 mg sodium lactate per liter of ground water treated, based on concentrations of major electron acceptors (e.g. nitrate, sulfate, bicarbonate).

➢ Estimated volume of water to be treated: 210,000 gallons, based on geospatial modeling.

➢ Safety factor of 10 used to account for dilution, and incomplete use of lactate by biological processes.

➢ 60% sodium lactate is being added as a 2% solution to the injection well via a piping manifold.
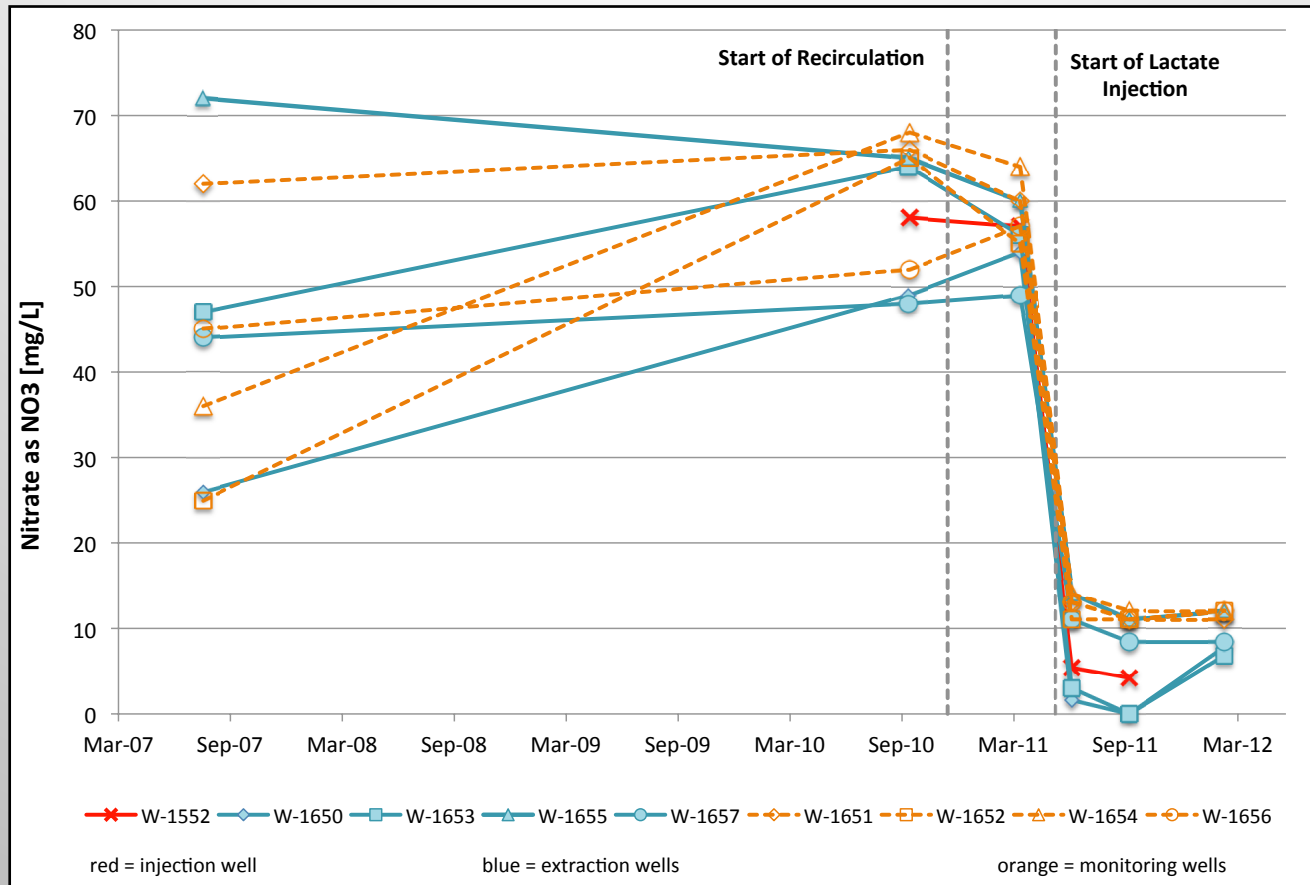
Current Status

Recirculation System Performance

➢ Sodium lactate injection results indicate that the subsurface chemistry can be easily altered in the preferential flow pathways in a short period of time and the circulation cell needs to remain operational to achieve favorable conditions for in-situ bioremediation in lower permeability units.

Current Status (continued)
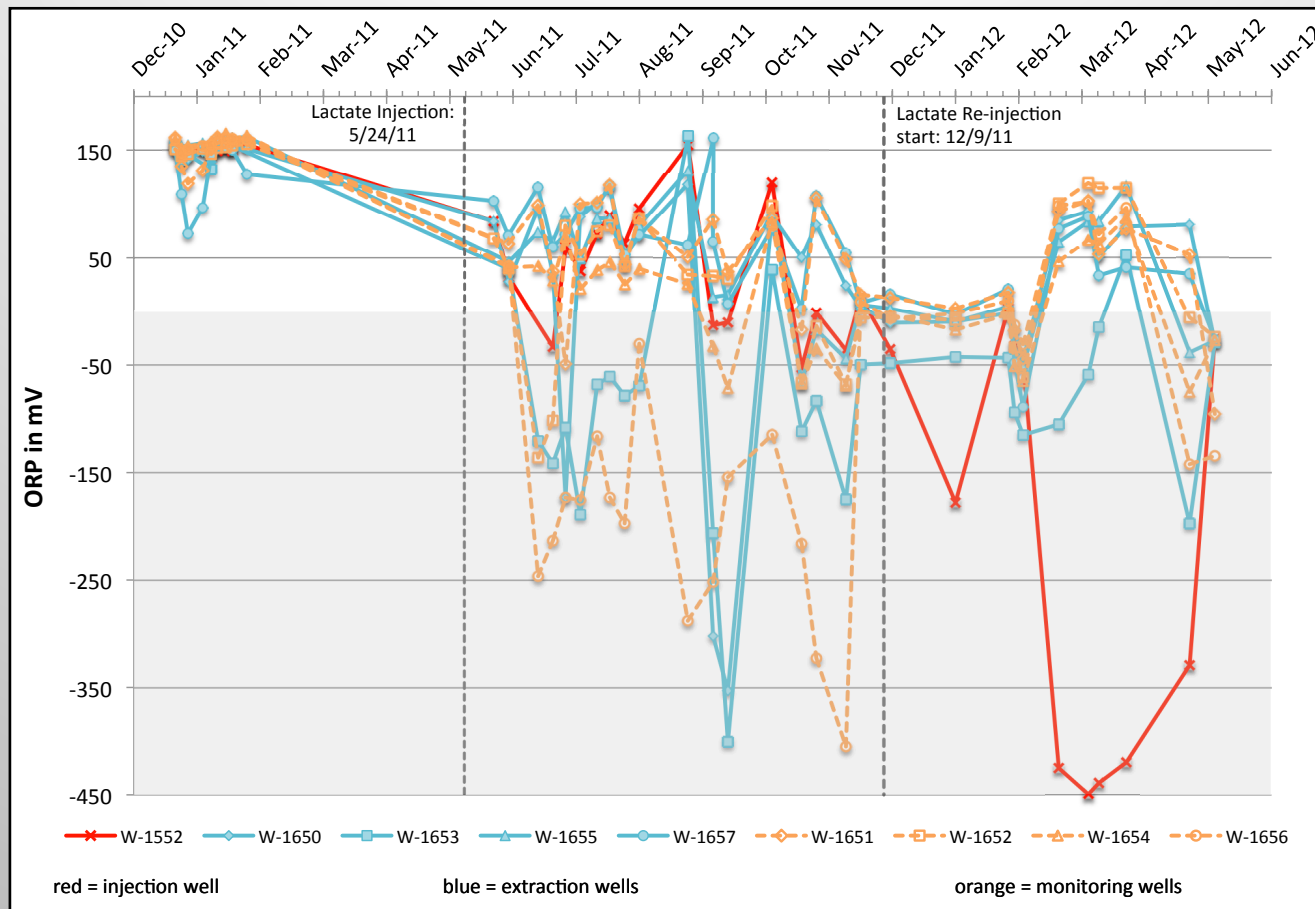
> Oxidation Reduction Potential decreased from pre-test conditions of +150 mV to less than -25 mV in all wells.

Current Status (continued)

> Nitrate concentrations in ground water indicate subsurface is reaching anoxic conditions.

Current Status (continued)

➢ Sulfate concentrations in ground water remained unchanged (~100 mg/L), indicating that strongly reducing conditions have not been achieved yet.

➢ Biofouling of injection well W-1552 and possibly more permeable sand deposits has resulted in decreased injection and extraction flow rates.

➢ System optimization during 2011: Injection and extraction well redevelopment through mechanical agitation and injection of liquid chelating agent LBA (glycolic acid).

Next Steps

Bioaugmentation

➢ Once the sulfate concentrations reduce and strongly reducing conditions are achieved, KB-1® will be used to bioaugment the system.

➢ Bioaugmentation will be followed by a secondary tracer study to determine the final distribution of KB-1® in the subsurface.

Next Steps (continued)

Long-term Monitoring Goal

➢ Determine the effectiveness of bioremediation in lower permeability units where bioremediation may not be as effective as in the preferential pathways due to limited delivery of sodium lactate and KB-1®.

Cleanup Time Estimation

➢ A numerical model of the site will be calibrated using the existing data from the past ex-situ operations and this study to estimate cleanup times under both remedial approaches. The model results will be used to provide a defensible life-cycle cost comparison of both approaches.

End Point

There are three questions that we hope to answer at the end of this treatability study:

①What is the role of heterogeneity in the long-term effectiveness of in-situ bioremediation?

②What is the permeability range where in-situ bioremediation is practical?

③How long do we have to maintain favorable conditions for in-situ bioremediation to achieve complete cleanup?